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Quantitative estimation of ventilation in newborn infants using the impedance pneumogram

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Changes in transthoracic impedance during breathing have been shown to bear a strong correlation to changes in lung volume in the adult [1–5]. If a linear correlation between tidal volume and changes in transthoracic impedance could be established for infants as well as adults, transthoracic impedance plethysmography would provide a non-invasive means of monitoring alterations of tidal volume during intensive care monitoring on newborn infants or during respiratory studies. The purpose of this report is to describe a method for validating the impedance plethysmograph as a means of estimating tidal volume in the newborn infant.

Curriculum vitae

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1 Methods

In impedance plethysmography [1], a high-frequency alternating current is passed through the chest, or other portion of the body, between two electrodes. Variations in the volume of the chest and its composition of air relative to tissue and fluid cause variations in the impedance of the chest. These variations of impedance in turn cause the current in the impedance plethysmograph to vary, and this signal may be recorded. In this study, the subjects were 8 healthy infants chosen at random from patients on the Neonatal Intensive Care Unit. All were being monitored by conventional methods for heart rate and respiratory rate. Birth weights range from 709 grams to 3506 grams, and all were of appropriate weight for gestational age. Each infant was swaddled and warmed by an infra-red lamp, and all were studied 30 minutes after feeding. Clinical data is summarized in Tab. I. No infant was ill at the time of study.

A surface electrode was coated with electrocardiographic paste (HEWLETT-PACKARD) and taped securely to each anterior axillary line at the angle of LOUIS [2, 3]. These leads were then connected to an impedance pneumograph (IMI) via standard RA and LA electrocardiographic leads. After a trial run to check electrode placement, the infant was allowed to breathe into a pediatric wedge spirometer (MED-SCIENCES) with no measurable resistance, which had been calibrated by means of a repeating syringe. Both the impedance pneumograph and spirometer were then connected to a four channel polygraph (HEWLETT-PACKARD) and

a simultaneous tracing of respiratory activity made by spirometry and impedance pneumography. Breathing was recorded for two to three minutes. A two- to threefold variation in tidal volume was usually obtained as the infant breathed into the spirometer mask. At the end of the test the spirometer was calibrated physically with a 10 cc. repeating syringe. Groups of 8 to 10 breaths at 30 to 45 second intervals were then measured. Spirometric volume in cubic centimeters was plotted against the corresponding deflection obtained from the transthoracic impedance pneumogram. Standard statistical techniques [6] were used to calculate Pearson's correlation coefficient (r), standard error of estimate of y on x (Sy.x) and values of p for Student's t test. These results are presented in Tab. I.

2 Critique of the method

The exact factors which determine the transthoracic impedance are unknown [1, 2]. In addition to the alterations in impedance associated with changes in the volume of gas within the chest, changes in impedance are also associated with variations in the blood volume of the chest. Therefore, where tidal volume is small in relation to cardiac stroke volume, cardiac activity may contribute significantly to the changes in transthoracic impedance detected by the plethysmograph. This is a special problem where respiratory rate approaches cardiac rate. Although rarely a problem in the adult this is of special importance in the premature infant where tidal volumes are small and respiratory frequency is high.

Positioning the electrodes is of great importance [2]. The electrodes are sensitive not only to placement, but also to body position and to the mode of breathing. Alterations in the shape of the thorax can alter the type of signal perceived by the plethysmograph. Although the electrodes may be left in place for hours, if necessary, prolonged use requires frequent recalibration if quantitative results are to be obtained.

Two major types of artifacts occur. These are illustrated in Figs. 1 and 2. Fig. 1 illustrates a satisfactory tracing with a large sigh occurring near the beginning of the tracing. Sighs are apparent to the observer, and their presence should be recorded on the tracing. Movement artifacts are recorded in Fig. 2 near the end of the plethysmograph tracing.

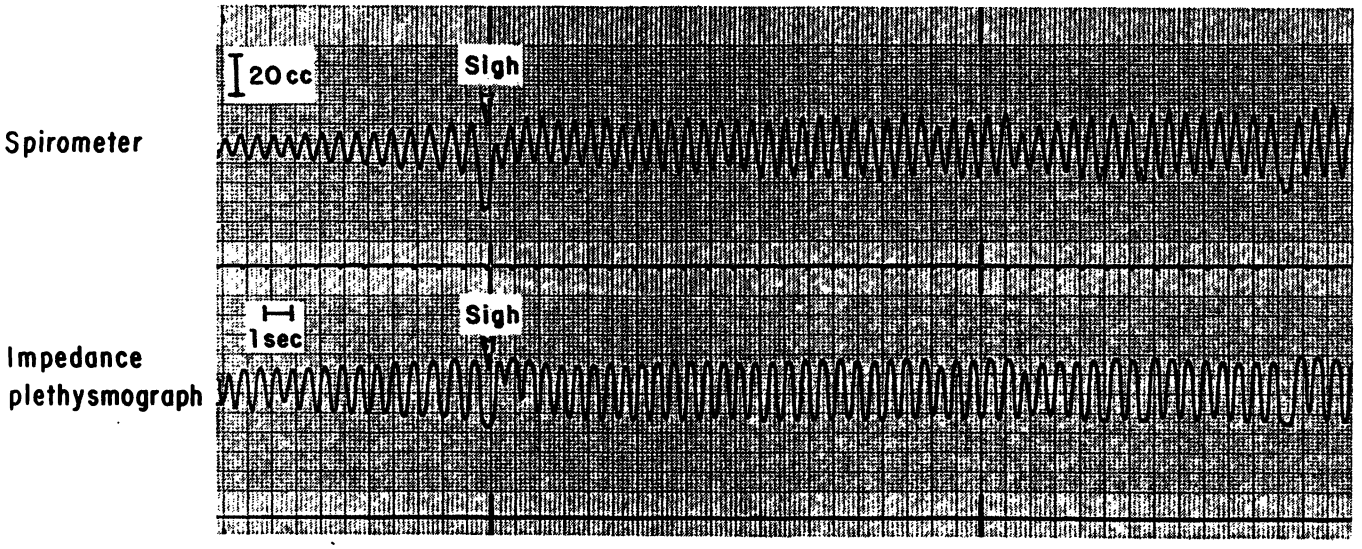

Fig. 1. A technically acceptable tracing comparing tidal volume measured by wedge spirometry (upper trace) and impedance plethysmography (lower trace). Inspiration is downward on both traces.

Tab. I. Correlation data obtained on study infants.

Infant number	Birth weight (grams)	Study weight (grams)	Age at study (days)	Range of tidal volume (cc)	Range of respiratory frequency (breath/minute)	Number of breaths (n)	r	p	Syx
1A	3560	3460	11	5–15	60–70	30	.90	< .001	1.15
1B		3460	11	6–16	80–90	38	.93	< .001	1.33
1C		3460	11	22–44	60–90	20	.94	< .001	2.40
2	1100	1100	7	8–25	80–100	24	.85	< .001	3.49
3	709	2030	84	5–25	54–65	36	.86	< .001	1.36
4	1190	1300	19	10–16	91–102	30	.66	< .001	0.87
5	1150	1310	22	6–13	86–100	30	.90	< .001	0.99
6	1900	1900	11	9–29	67–84	29	.50	< .01	2.41
7	2880	2690	11	18–29	60–70	23	.57	< .005	1.61
8	2260	2180	16	8–19	75–100	33	.92	< .001	1.32

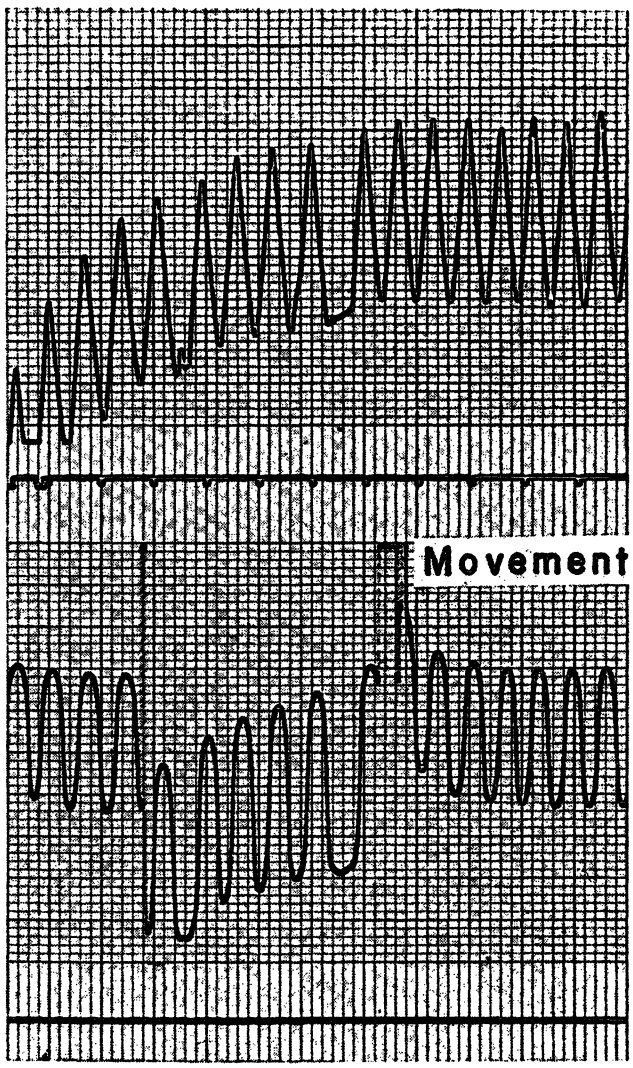

Fig. 2. Upper trace obtained by wedge spirometry compared with lower trace obtained with impedance plethysmogram. Note lack of correspondance due to movement artifact.

In the infant these are usually due to vigorous stretching or reaching movements of the arms, legs, and trunk, and are also easily noted.

3 Results

Clinical and statistical data is presented in Tab. I. In seven of the 10 studies a strong positive correlation coefficient was obtained ($r > 0.85$). The statistical significance of this correlation was generally very high ($p < 0.01$). Fig. 3 depicts a correlation diagram obtained from an infant whose tidal volume ranged between 8 and 19 cc.

4 Discussion

These results demonstrate that transthoracic impedance plethysmography is a reliable estimate of tidal volume and minute volume in the newborn infant. It can thus be used for quantitative estimation of minute volume during intensive care monitoring, and may be of special value in evaluating changes in blood gas tensions in patients with congenital heart disease or respiratory distress syndrome. This method has already been used to evaluate the presence of respiratory reflexes [8] and apnea [9] since it has the advantage of avoiding stimulation of the infant's face by masks or nose valves. Transthoracic impedance plethysmography is a method which deserves wider use in the care and study of the neonate.

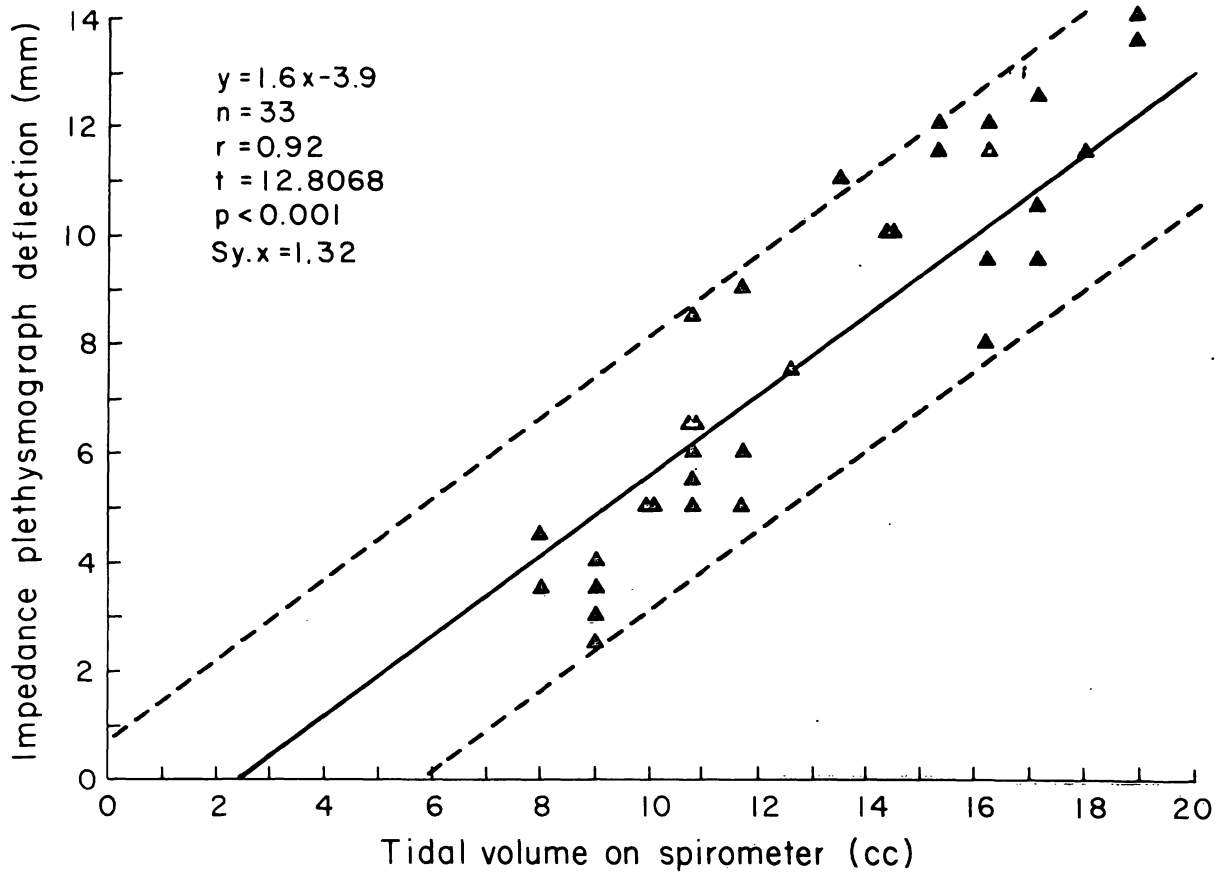

Fig. 3. Plot of calibration data obtained from infant 8.

Summary

Impedance pneumography is potentially a non-invasive method of measuring infant tidal volumes. In order to evaluate the accuracy of impedance pneumography, eight healthy infants (weighing from 709 to 3506 grams) were randomly chosen and studied. Simultaneous measurements of tidal volumes were made by calibrated spirometry and by transthoracic impedance pneumography. The results were statistically compared. Transthoracic impedance pneumography provided a reliable estimate of tidal and minute volumes in these newborn infants.

Keywords: Electronics (medical), newborn infants, plethysmography, respiratory function tests, spirometry.

Zusammenfassung

Quantitative Bestimmung der Ventilation bei Neugeborenen mit dem Impedanz-Pneumographen.

Die Impedanz-Pneumographie ist im Prinzip eine nicht-invasive Methode, um das kindliche Atemzugvolumen zu messen. Nach den Gesetzen des Zufalls wurden 8 gesunde Neugeborene (mit einem Gewicht zwischen 709 und 3506 g) ausgewählt und untersucht, mit dem Ziel, die Meßgenauigkeit der Impedanz-Pneumographie zu ermitteln. Durch die kalibrierte Spirometrie und eine transthorakale Impedanz-Pneumographie wurden simultane Messungen der Atemzugvolumina vorgenommen. Die Resultate wurden statistisch verglichen. Die transthorakale Impedanz-Pneumographie ermöglichte eine zuverlässige Bestimmung der Atemzugvolumina und des Minutenvolumens bei diesen Neugeborenen.

Schlüsselwörter: Neugeborenes, Medizinische Elektronik, Plethysmographie, Respiratorische Funktionsteste, Spirometrie.

Résumé

Estimation quantitative de ventilation chez les nouveaux-nés par pneumogramme d'impédance

La pneumographie d'impédance est virtuellement une méthode non invasible de mesure des volumes de respiration chez les bébés. Afin d'évaluer la précision de la pneumographie d'impédance, 8 nouveaux-nés sains (pesant entre 709 et 3506 g) ont été choisis au hasard pour être soumis à étude intensive. Des mesures simultanées des volumes de respiration ont été réalisées par spirométrie calibrée et par pneumographie d'impédance transthoracique. Les résultats ont fait l'objet d'une comparaison statistique. La pneumographie d'impédance transthoracique a fourni une estimation sûre des volumes-minute et de respiration chez ces nouveaux-nés.

Mots-clés: Electronique médicale, nouveaux-nés, pléthysmographie, spirométrie, tests de fonction respiratoire.

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